Mechanical Technology Development on A 35-m Deployable Radar Antenna for Monitoring Hurricanes

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Introduction—NIS Project

The NEXRAD in Space (NIS) project develops a novel instrument concept and the associated antenna technologies for a 35-GHz Doppler radar to monitor hurricanes and severe storms from a geostationary orbit.

- First generation of geostationary orbiting radars for monitoring hurricanes and convective storms throughout their life cycles
- Ka-band, Doppler radar for vertical profiling of hurricane rainfall intensity and motion
- Pulse compression to increase measurement sensitivity without using high peak power
- 35-m, light-weight, high packaging efficiency, deployable antenna reflector
- Spherical antenna aperture with spiral-scanning feeds to obtain area coverage
- Separate transmit/receive antenna feeds to overcome range delay between transmit pulses and received signals

Introduction—NIS Project

- Science Objectives:
  - Measure hurricane precipitation intensity, dynamics, and life cycle for improved model prediction of track, intensity, and rain rate
  - Provide data for improved prediction of hurricane-induced floods

- Practical Benefits:
  - Save lives / enhance public safety
  - Improve emergency response capability and reduce false-alarm
  - Optimize emergency resource utilization and cost benefits
  - Mitigate property loss
  - Other economic impacts (e.g., insurance coverage…)

35-Meter Reflector

Extremely stringent requirements:

- Large aperture size (35 meters in diameter)
- High surface accuracy (0.17 mm RMS for 35 GHz operations)
- Lightweight (targeted reflector weight is < 200 kgs)
- High launch packaging efficiency and space deployable

Exceed current state-of-the-art of large space reflectors

Shape Memory Polymer Reflector

Shape Memory Polymer materials:

- State-of-the-art with a broad range of very unique characteristics.
- Can be utilized for future development of ultra lightweight, extremely large, high-precision, high-packaging efficiency space structures.
- They retain memory of their as-manufactured state.
- When heated to above their glass transition temperature (Tg) — pliable and can be compactly packaged.
- Upon cooling — retain their packaged state.
- When reheated to above their Tg — become pliable and deploy back to their original shape.

Shape Memory Polymer Reflector

A very sophisticated study — investigate the feasibility of using SMP materials to develop the high precision 35-m diameter reflector:

- Brainstorming — flush out innovative ideas.
- Seven concepts were developed from these ideas.
- A list of trade parameters were established.
- A trade study was performed.
- The best architecture was identified.
- A preliminary design and analysis was performed for the identified architecture.
- Feasibility was demonstrated and developing directions were determined.

Shape Memory Polymer Reflector

Trade parameters:

- Reflector surface accuracy — the ability of the reflector surface to achieve and maintain the desired shape (after deployment and rigidization) in the operational environment.
- Support structure accuracy — the ability of the structural components to achieve and maintain dimensional accuracy and position and provide structural stiffness in the operational environment.
- Controlled deployment — the ability to be deployed (multiple times) in a controlled and predictable fashion.
- Packing:
  - the ability to fit within the defined launch vehicle,
  - compact ratio,
  - easy of packing.

Shape Memory Polymer Reflector

Trade parameters (cont.):

- Mass — the ability to achieve operational mass requirements
- Scalability — be enlarged or reduced in size with little or no reconfiguration — scaled down for test and scale up for potential missions.
- Ground testability — ease to conduct ground testing for system validation:
  - 1-g deployment,
  - support equipment for ground testing,
  - antenna accuracy under 1-g environment.
- Design flexibility — the ability to adapt to alternative design options (materials and/or configurations).
- Complexity/reliability/risks — evaluates the mission risks and is based on preliminary parts count and maturity (TRL) level of each technology.
- Cost — the ability to achieve all operational/mission requirements within the budgeted cost.

Shape Memory Polymer Reflector

Trade study results:

NEXRAD in Space Spherical Reflector Trade Study										
Trade Parameters	Weight	Concept Designation								
		Concept 1	Concept 2	Concept 3a	Concept 3b	Concept 3c	Concept 4	Concept 5	Membrane	AstroMesh
Reflector Surface Accuracy	1	6	6	6	6	6	6	5	1	9
Support Structure Accuracy	1	9	9	9	9	9	9	7	3	10
Controlled Deployment	0.8	6	7	8	8	9	9	7	3	10
Packing	0.8	8	8	8	8	8	7	7	10	7
Mass (Specific Mass)	0.6	8	8	6	6	6	7	9	10	6
Scalability	0.6	9	9	8	8	8	8	5	2	6
Ground Testability	0.6	9	9	9	9	9	9	2	1	9
Design Flexibility	0.6	9	8	6	7	7	6	5	4	5
Complexity/Reliability/Risks	0.8	8	8	7	7	7	7	5	5	6
Cost	0.4	8	7	4	4	4	7	5	7	4
Total		56.8	56.6	52.4	53	53.8	54.2	41.8	31.4	54.6
Rank		1	2	7	6	5	4	8	9	3

Concept (1), ranked no.1, selected for preliminary study

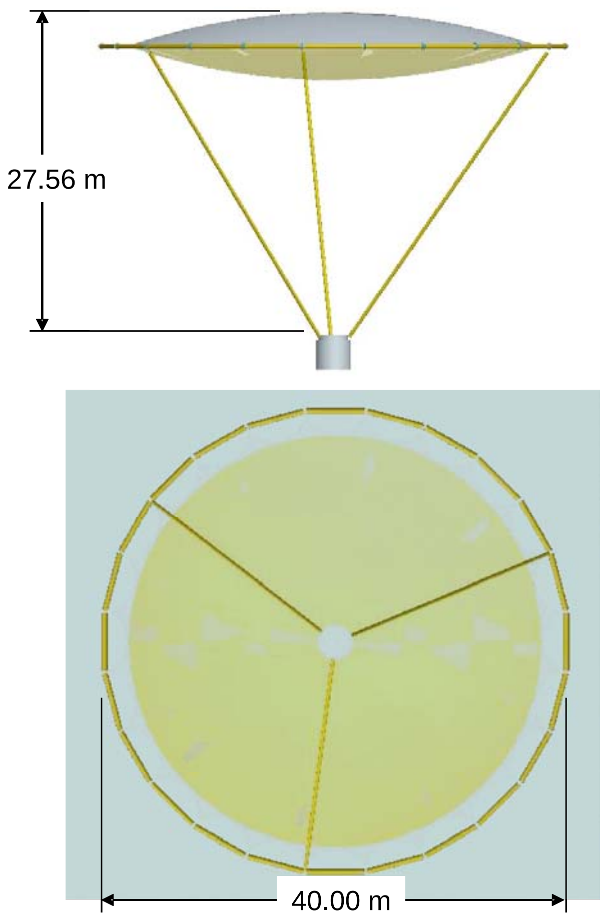
Shape Memory Polymer Reflector

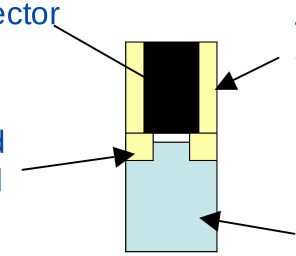
Preliminary design and analysis of the identified architecture:

- material identification and evaluation,
- preliminary mass analysis,
- preliminary antenna reflector accuracy analysis,
- deployed and stowed configuration,
- stowed volume.

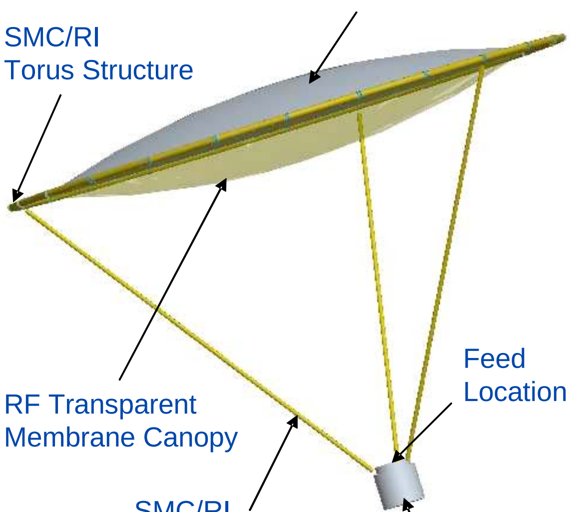
Shape Memory Polymer Reflector

Deployed configuration





Stowed configuration



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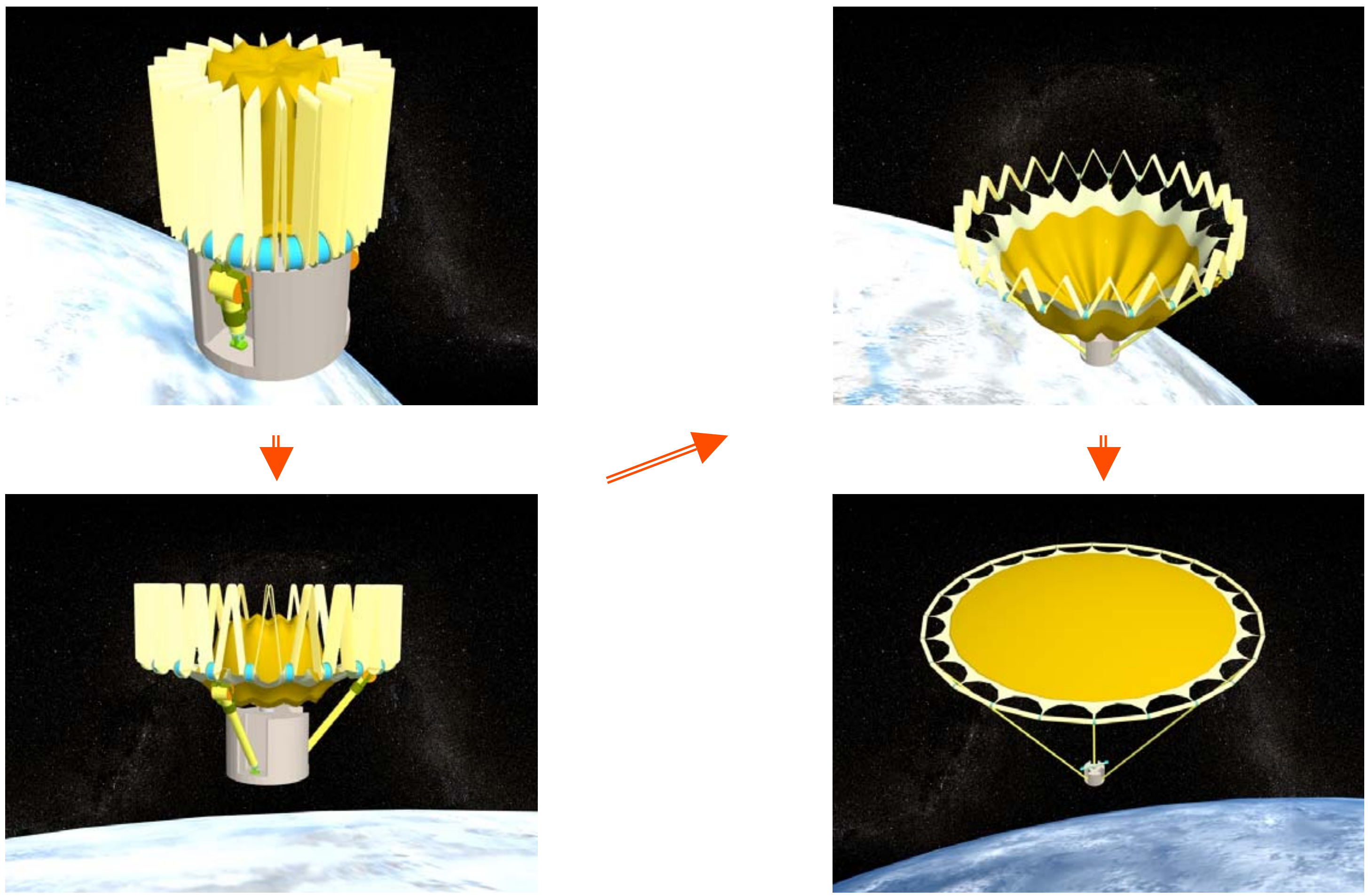
Shape Memory Polymer Reflector

Deployment process



Feeder Spiral Scanning Mechanism

The NIS instrument — a novel observational architecture:

- both reflector and spacecraft remain stationary
- antenna feeds perform spiral scan maneuver up to 4^o
- it covers a 5300-km circular disk on the earth surface
- it allows continuous and smooth transition between adjacent radar footprint coverage
- one complete disk scan takes a total of 200 spirals

Feeder Spiral Scanning Mechanism

Development of spiral scanning mechanism:

- generate scanning mechanism concepts
- conduct trade studies against NIS requirements
- down select a baseline concept for hardware development
- design, fabricate, and assemble a full-scale engineering model
- carry out performance evaluations and tests.

Feeder Spiral Scanning Mechanism

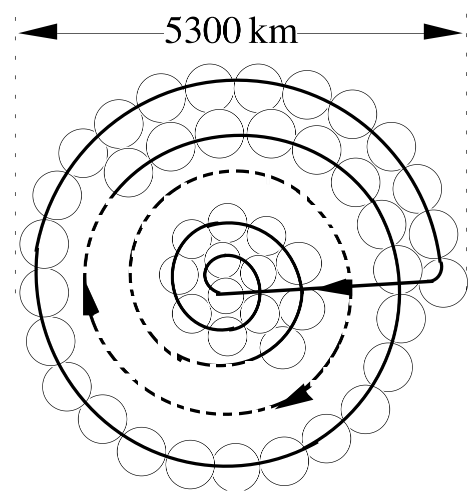
Three mechanism concepts were generated:

- Concept one: Helix Track
- Concept two: Rotating Bar
- Concept three: Double Rotating Bars

Feeder Spiral Scanning Mechanism

Concept one: Helix Track

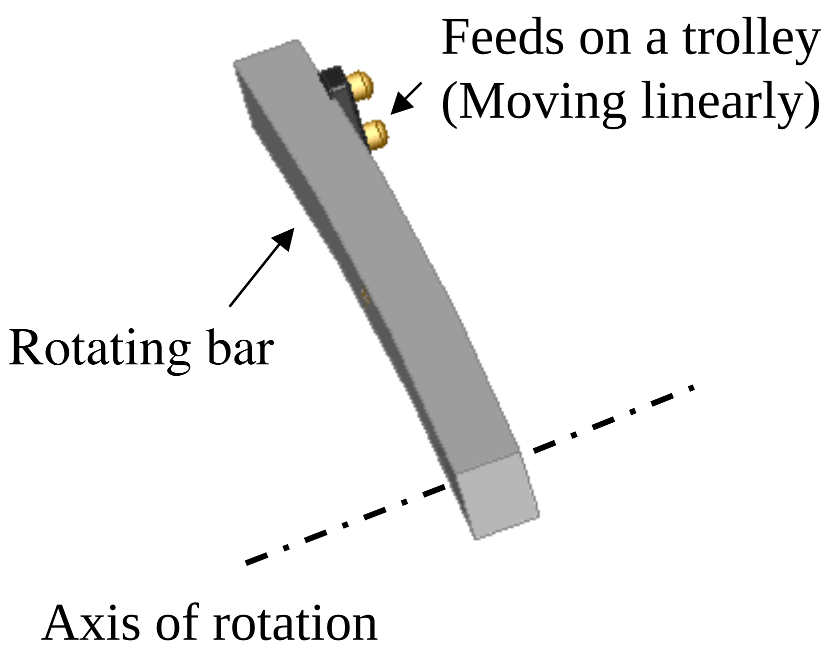
Fixed helix track

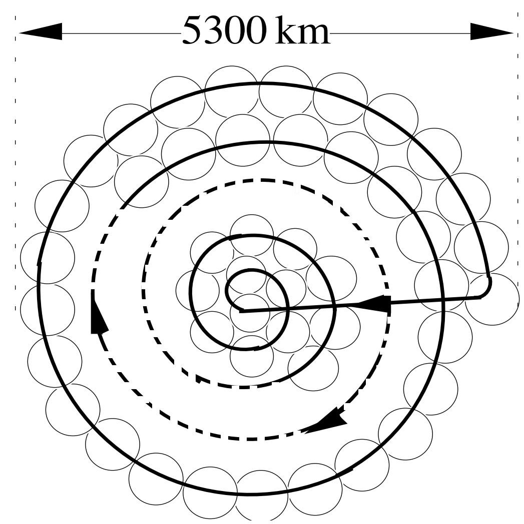


Scan pattern

Feeder Spiral Scanning Mechanism

Concept two: Rotating Bar

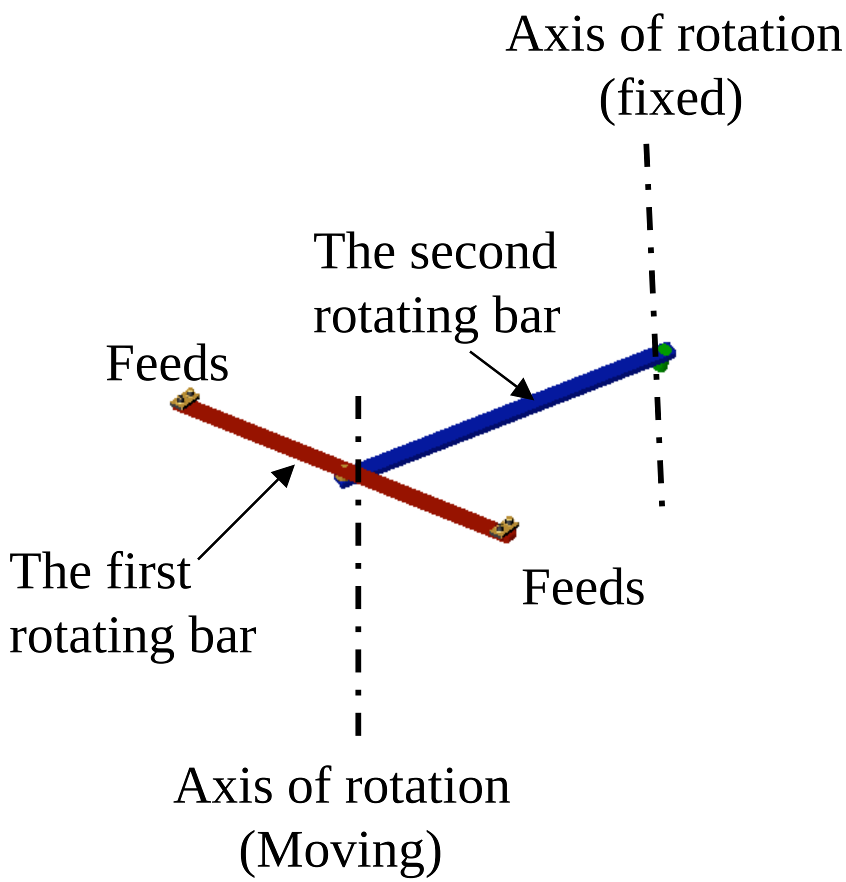




Scan pattern

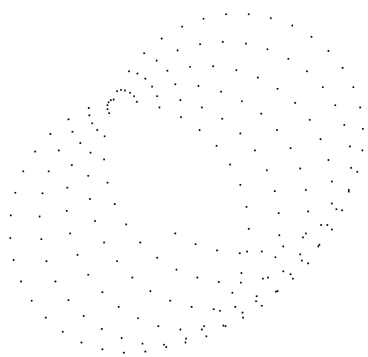
Feeder Spiral Scanning Mechanism

Concept three: Double Rotating Bars

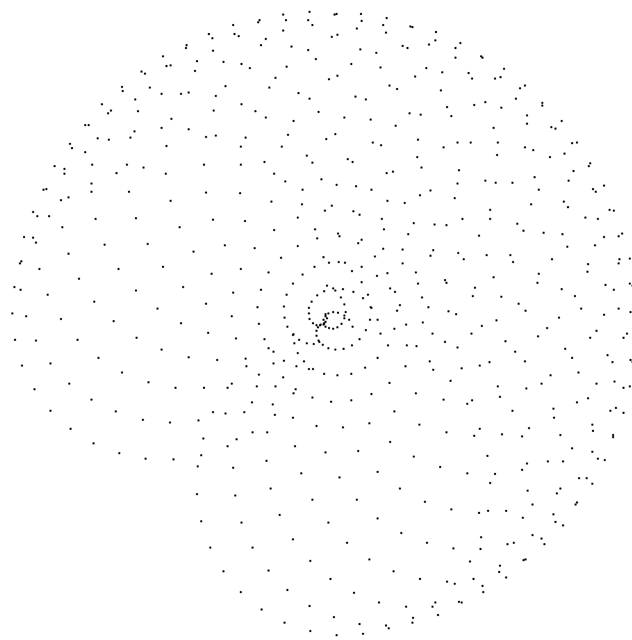


Feeder Spiral Scanning Mechanism

Concept three: Double Rotating Bars



Motion of the feeds



Radar scan pattern

Feeder Spiral Scanning Mechanism

Baseline architecture

Rotating Bar architecture has been modified to have two sets of feeder and identified to be the baseline architecture:

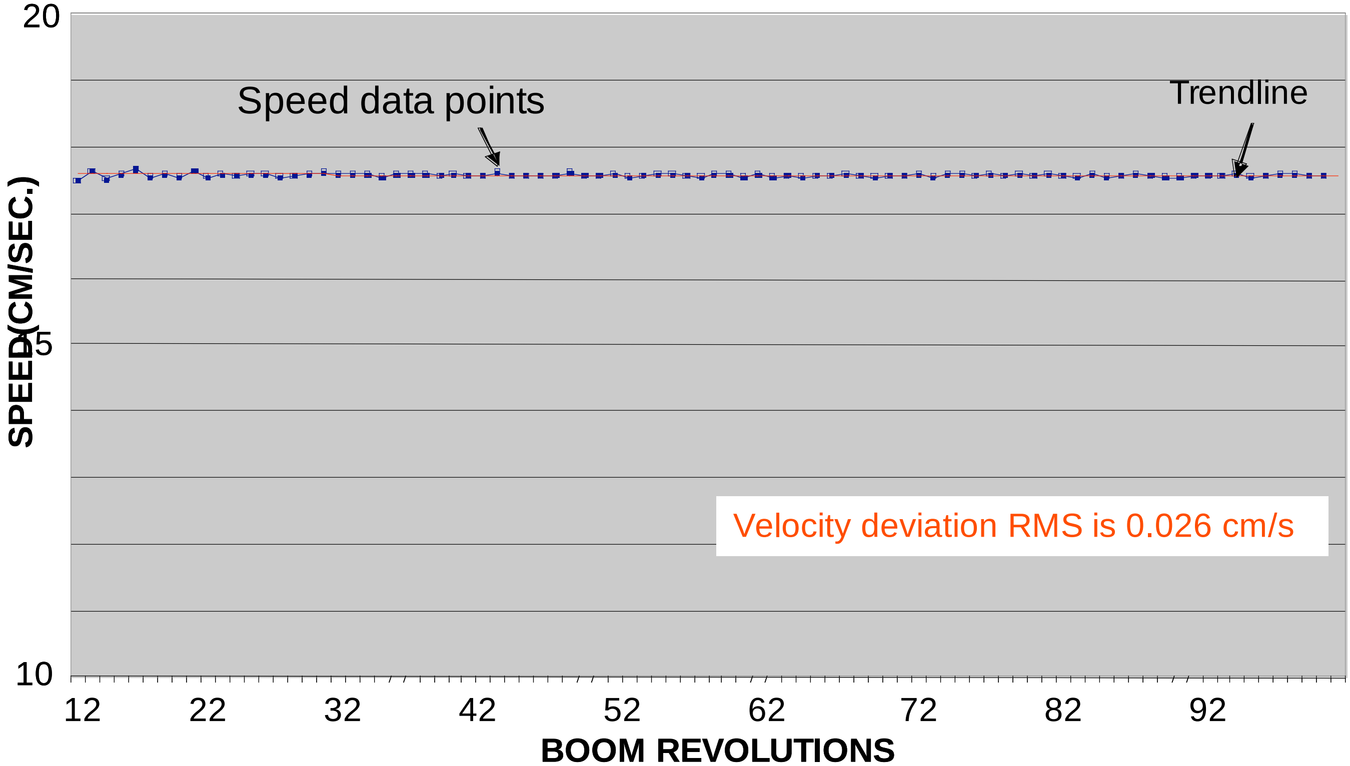
- two sets of feeder produce two parallel spiral traces
- self-balance of the centrifugal forces created by feeders
- no significant oscillatory forces will be loaded to the spacecraft
- two sets of feeder will double the footprints with every revolution — the spiral speed can be reduced to half
- two sets of feeder offers a much quieter and smother scanning mechanism.

Feeder Spiral Scanning Mechanism

Full-scale engineering model

Feeder Spiral Scanning Mechanism

Performance evaluation



average speed = 17.57 cm/sec
velocity deviation RMS = 0.026 cm/sec
velocity deviation = 0.15% of the average spiral speed
the architecture is satisfactory

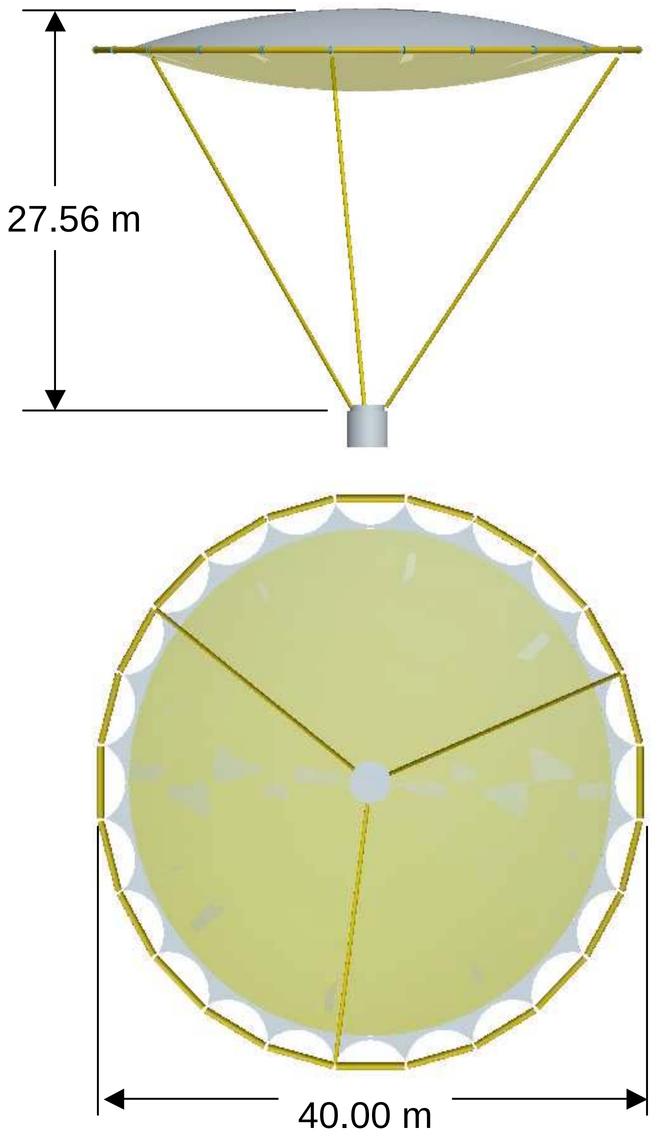
Conclusions:

- Shape memory polymer reflector technology is very attractive.
- Shape memory "rigidizable" is a key enabling technology which will make future extremely large and high packaging efficiency deployable reflectors possible.
- The high precision of spiral scanning mechanism has been experimentally verified.
- As a conclusion of this study, the mechanical aspect of the innovate NIS instrument concept is feasible.

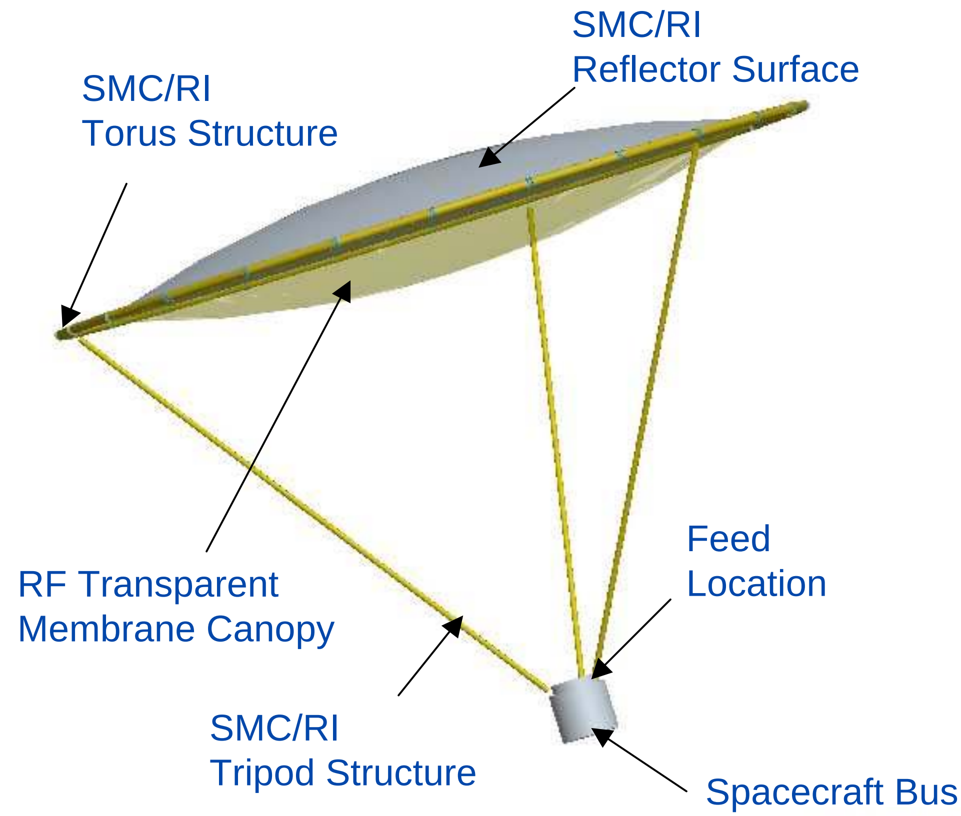
End

Back Up Slides

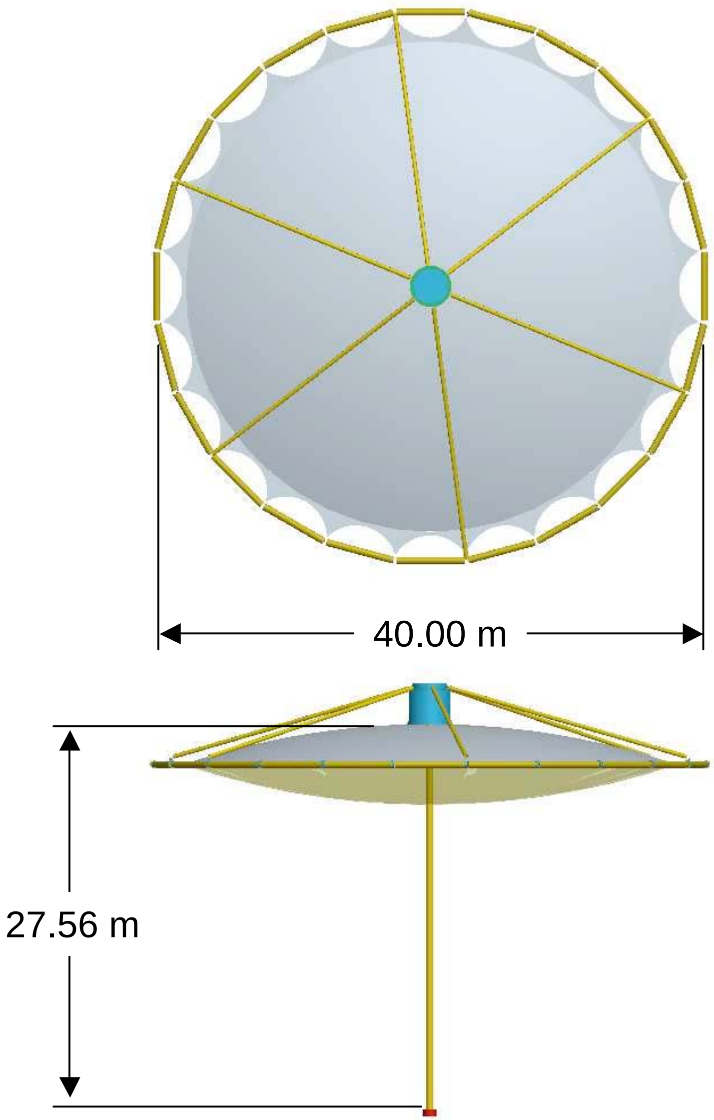
Concept 1 – Torus & Tripod Support



Design Description:
- Shape Memory Composite/Rigidizable-Inflatable spherical reflector with RF transparent membrane canopy
- RI reflector supported by SMC/RI perimeter torus
- The reflector system is connected to the spacecraft bus via the tripod structure
- Transmit and receive feeds are located on SC bus

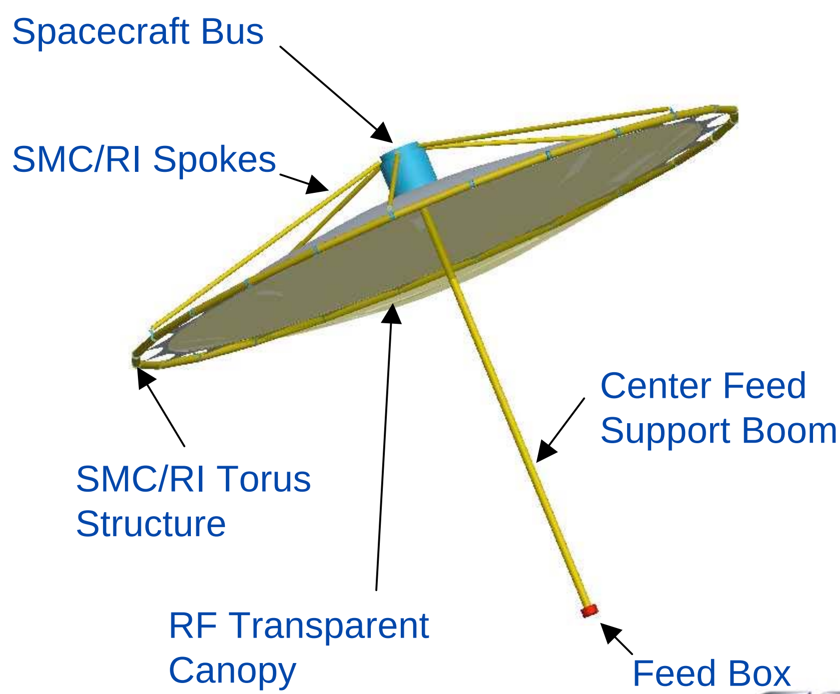


Concept 2 – Torus & Spoke Support



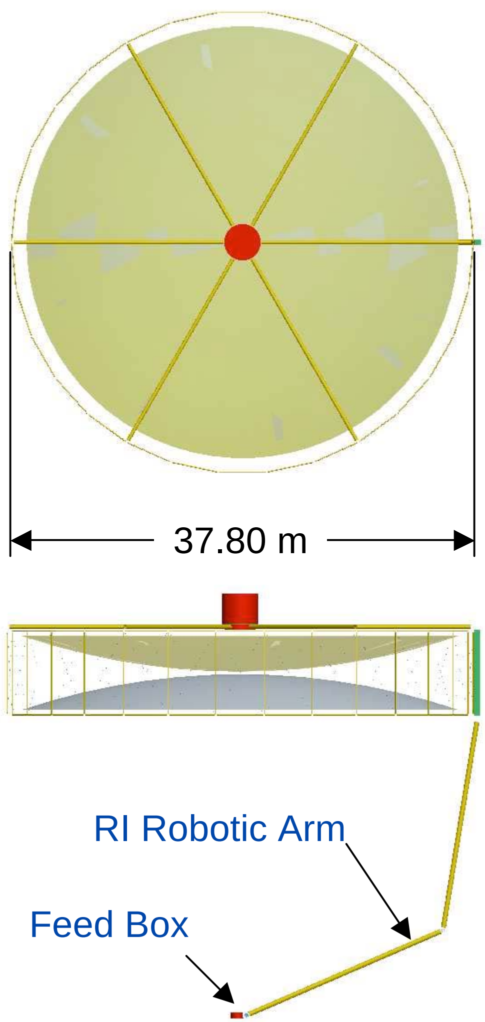
Design Description:

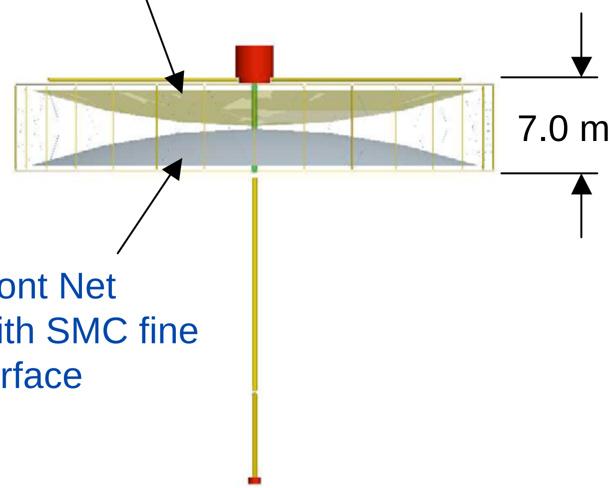
- Shape Memory Composite/Rigidizable-Inflatable spherical reflector with RF transparent membrane canopy
- RI reflector supported by SMC/RI perimeter torus
- The reflector system is connected to the spacecraft bus via RI spoke booms
- SC bus located behind the reflector surface
- Transmit and receive feeds are located in the feed box and connected to the SC bus via a center RI boom

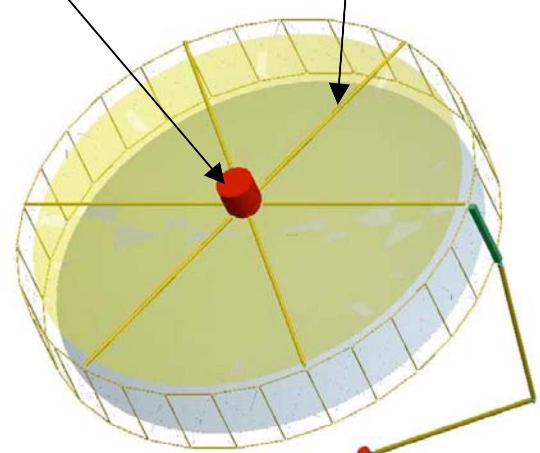


Concept 3a – Perimeter Truss & Robot Arm

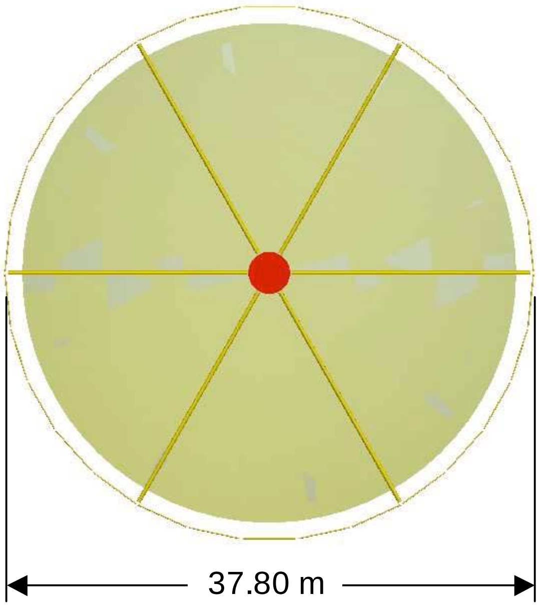
Design Description:
- Wire mesh reflector with shape memory composite fine surface
- SMC reflector supported by SMC/RI perimeter truss
- The reflector system is connected to the spacecraft bus via RI spoke booms
- Transmit and receive feeds are located in the feed box and positioned by a two-sectioned RI robotic arm

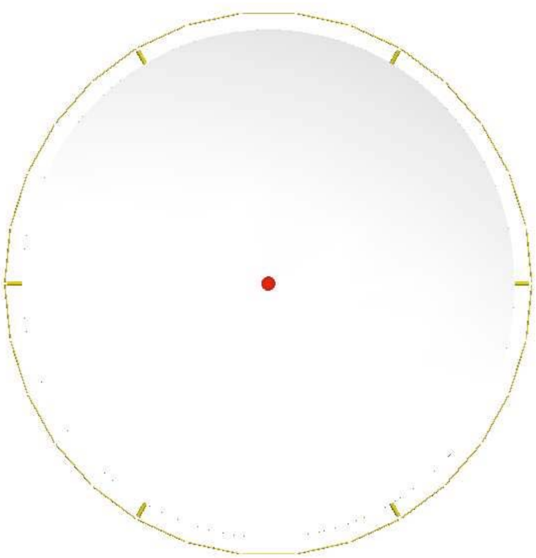






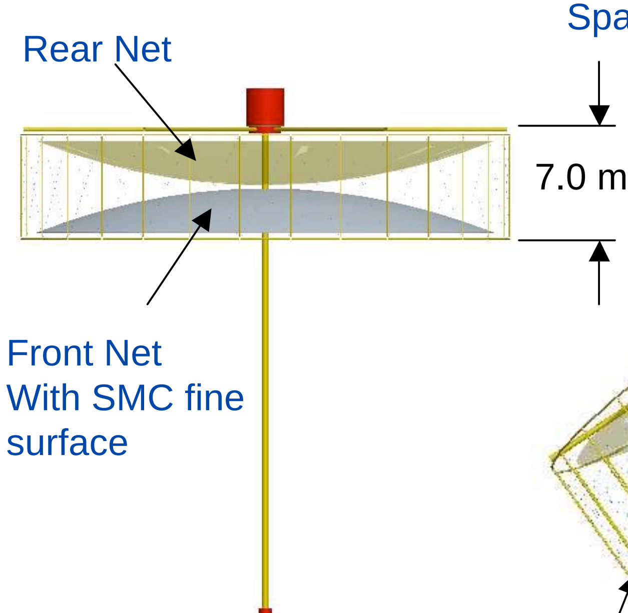
Concept 3b – Perimeter Truss & Spokes

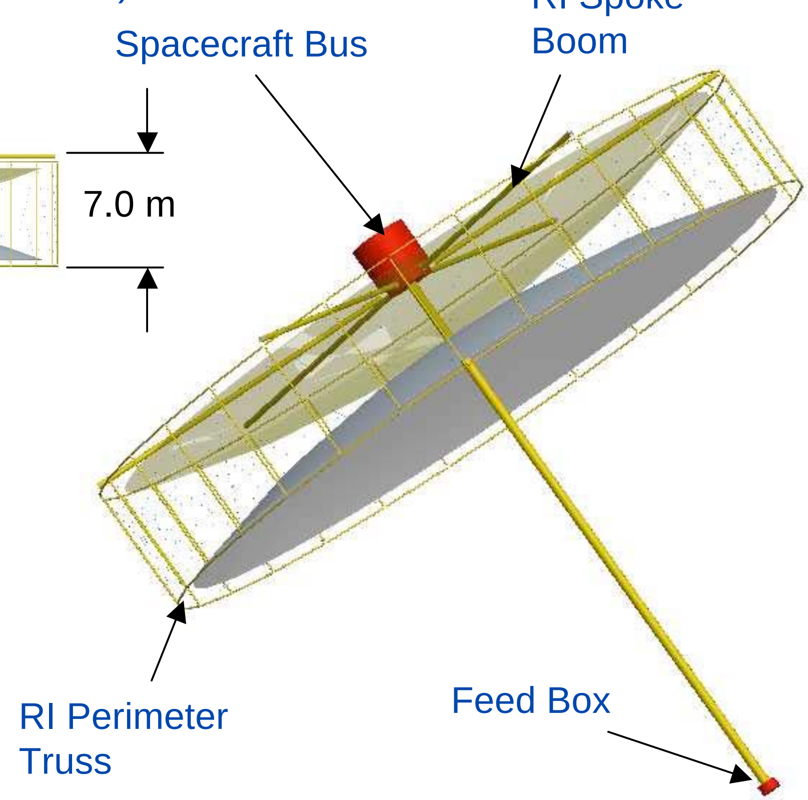




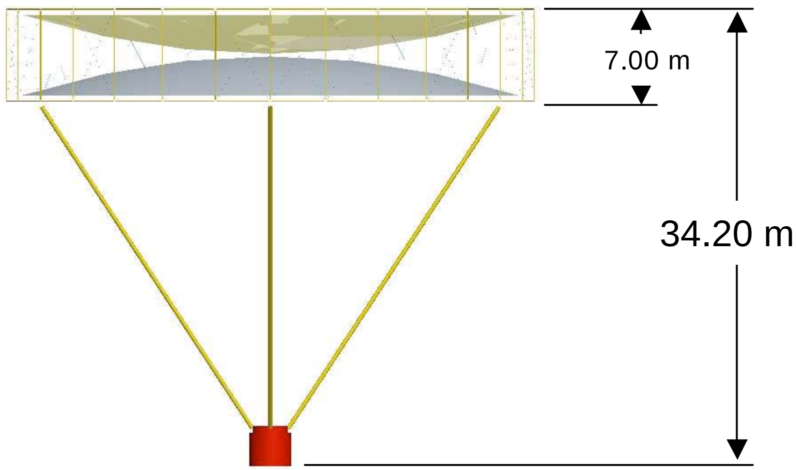
Design Description:

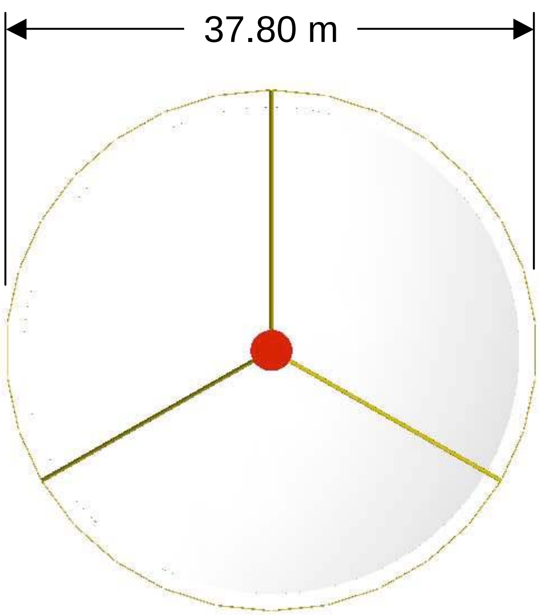
- Wire mesh reflector with shape memory composite fine surface
- SMC reflector supported by SMC/RI perimeter truss
- The reflector system is connected to the spacecraft bus via RI spoke booms
- Transmit and receive feeds are located in the feed box and positioned by a center RI boom (or truss)

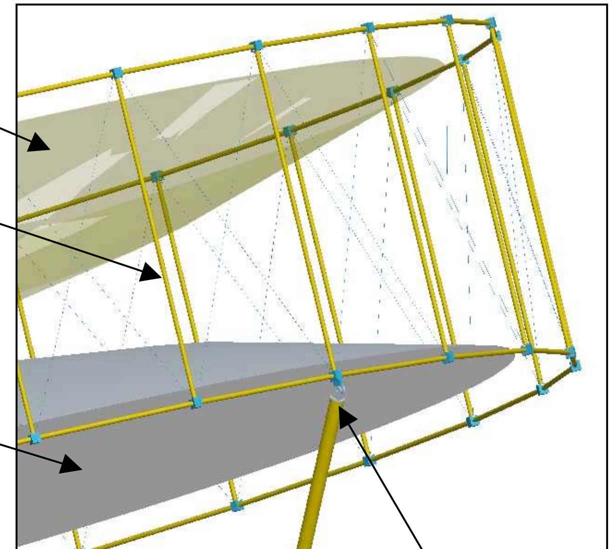




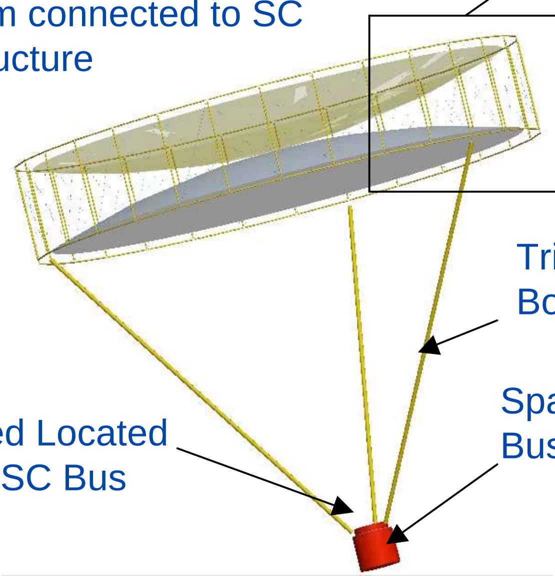
Concept 3c – Perimeter Truss & Tripod



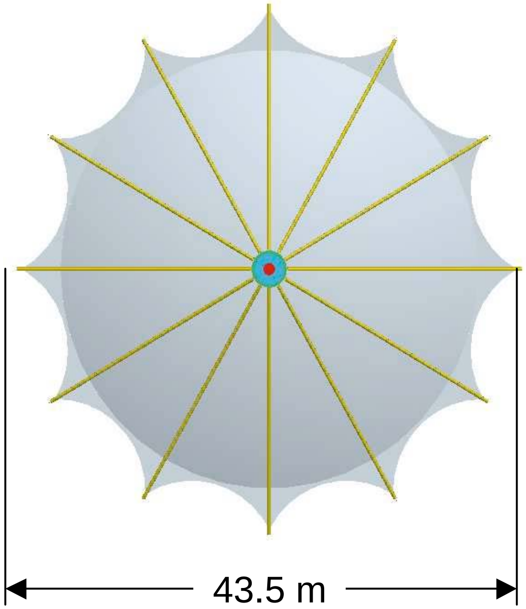


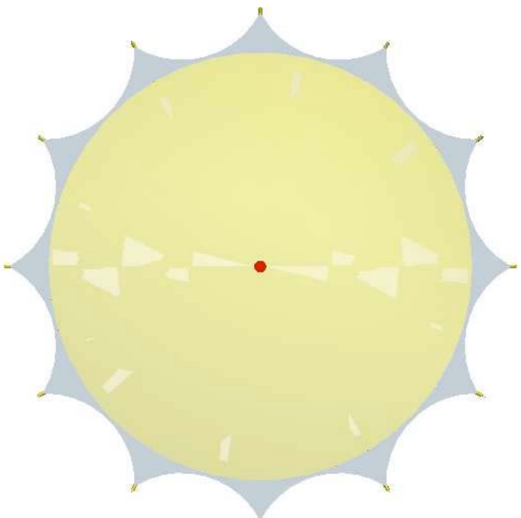


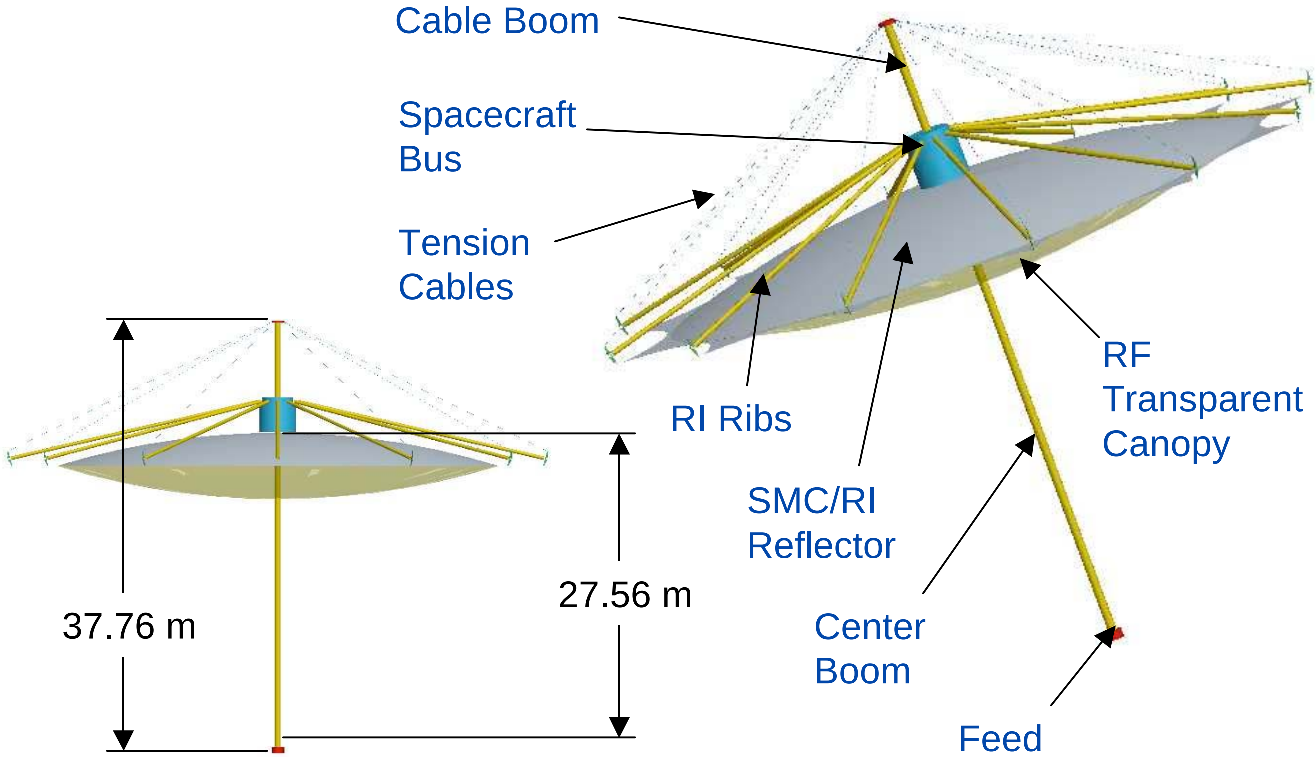
Design Description:
- Wire mesh reflector and perimeter truss same as concept 3a
- Reflector system connected to SC bus via tripod structure



Concept 4 – RI Ribs







Design Description:

- Shape Memory Composite/Rigidizable-Inflatable spherical reflector with RF transparent membrane canopy
- Spiral wrap RI ribs/spokes behind reflector surface (The ribs are loaded in compression)
- The reflector surface is supported by the SC bus at the center of the reflector and around the perimeter by the spokes
- Transmit and receive feeds are located in the feed box supported by a centralized RI boom (or truss)

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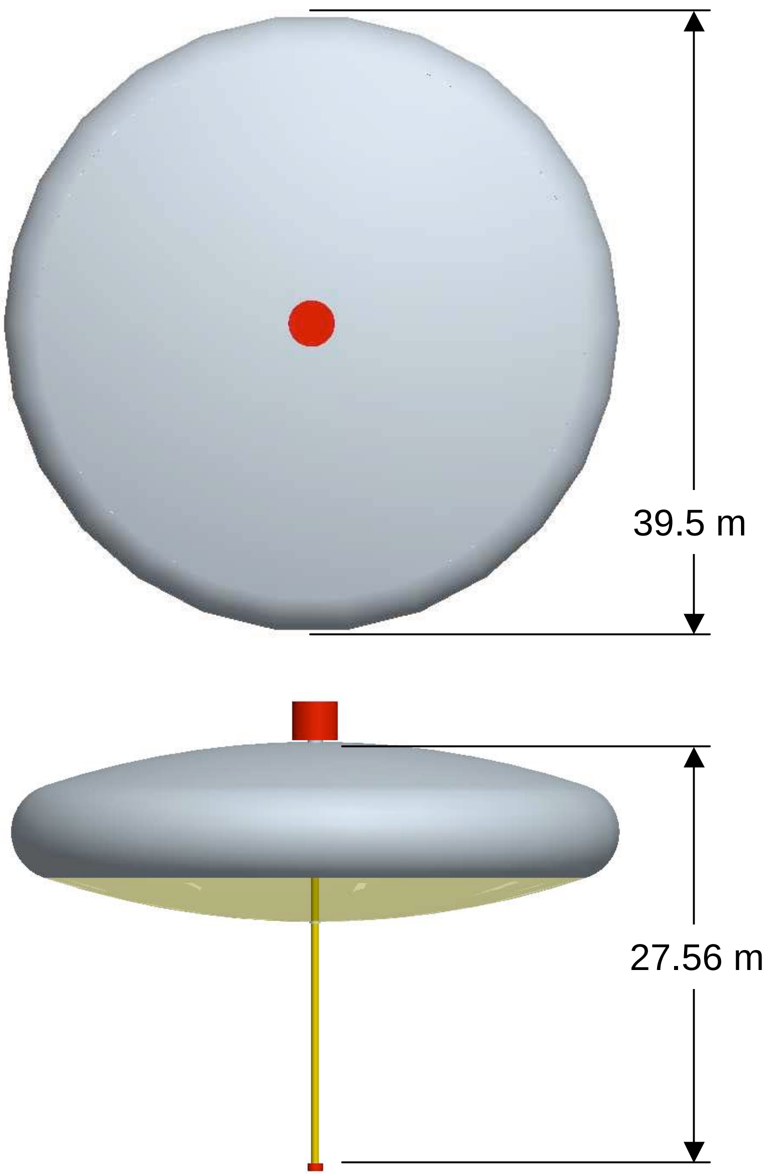
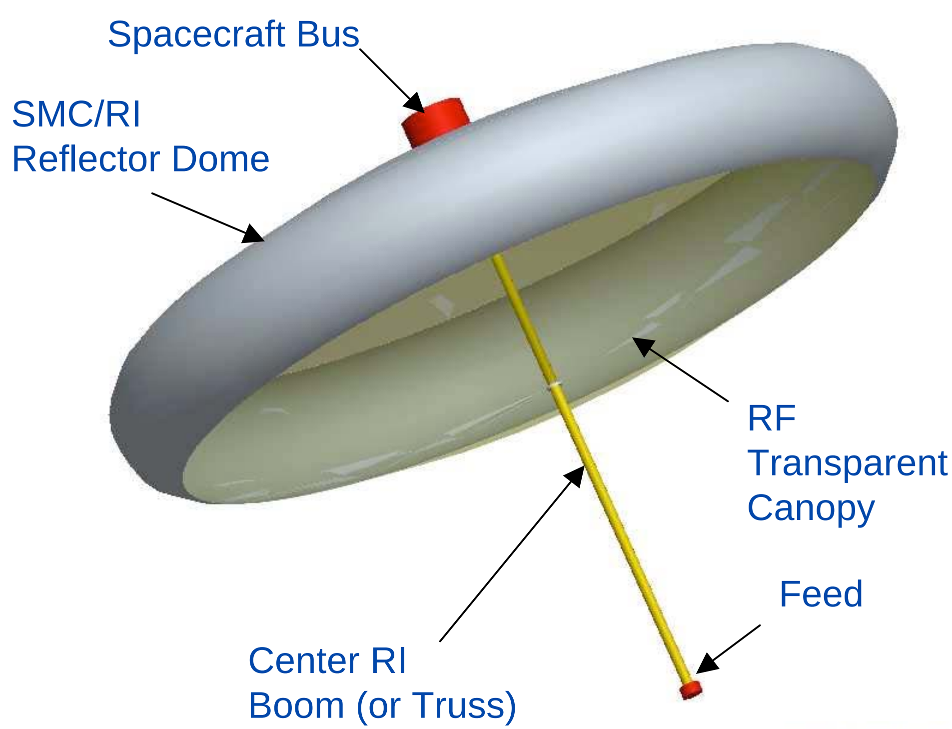
Concept 5 – RI Reflector Dome



Design Description:

• Shape Memory Composite/Rigidizable-Inflatable spherical reflector with RF transparent membrane canopy
• RI reflector forms the structural shell/dome
• The reflector system is connected to the spacecraft through the structural dome
• Transmit and receive feeds are located in the feed box supported by a centralized RI boom (or truss)



Introduction—NIS Project

NIS Instrument Concept and Innovations:

- Monitoring time evolution of rain & cloud from GEO (alt. = 36,000 km)
- 35-GHz, 4˚ spiral scanning radar to cover 5300-km diameter earth disk (equivalent to coverage of 48˚ latitude and 48˚ longitude)
- Deployable spherical aperture antenna to obtain 12 to 14 km horizontal resolution
- Innovative antenna scan strategy:
  - 1 transmit feed and 1 receive feed with fixed spacing to compensate for pulse delay
  - Scan by motion of 2 feeds on spiral path
    - Advantage over 2-D electronic scan, which requires millions of phase shifters
    - Advantage over mechanical rotation of entire antenna, which creates unacceptable torque
    - Advantage over S/C rotation, which requires custom-made, usually very expensive S/C
- Vertical resolution of 300 m using pulse compression
- Rain detection sensitivity: ~ 5 dBZ (after 100 sample averaging)
- Vertical Doppler profile measurements with 0.3 m/s precision
- One 3-D full-scan image once per hour
- Real-time processing to reduce downlink data volume/rate

Feeder Spiral Scanning Mechanism

Comparison of Mechanism Design Concepts

Concept	Advantages	Disadvantages
Helix Track	Single linearly moving system. Simple design and easily controlled motion.	(1) Difficult to implement; (2) introduce some RF blockage; (3) not easy to package and deploy this system for space launch; (4) quick return of the trolley to the center from the outer end of the spiral track is a challenge.
Rotating Bar	One linearly moving system and one rotational system. Relatively simple design and lighter weight.	Variable linear and rotational speeds. Unbalanced inertial force.
Double Rotating Bars	Both bars rotate at constant speeds. Good radar scan pattern.	Larger rotational inertia generates some unbalanced inertial forces.

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